Virtual, Mixed, and Augmented Survey – Germany

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1.0 INTRODUCTION

Augmented Reality (AR) and Virtual Environments (VE) have been introduced in the late 80s as innovative systems for displaying synthetic, computer-generated environments as if they were real. Various possible applications were identified soon, for instance: Product design, architecture, training, or teleoperation. But it turned out that computers' rendering power and display technology were too limited for a reasonable application then. The whole concept seemed to be a promising science-fiction topic that had come up too early for realization and practical use.

Nonetheless, technology evolved much faster. Less than a decade later, systems were powerful enough for first sample applications. Due to the huge demands on computing and rendering power (and resulting high financial expenses) they were just a small number of institutions doing research in this area. But again, it took only a short time until low-cost alternatives became available. The user community became much broader and, consequently, research and application activities were spread and intensified.

But while computing, rendering, and display technologies have made tremendous advance the design of the human-system-interface (HSI) did not. As a matter of fact, most systems still have to be run by special trained, qualified personnel, and most applications are often limited to passive presentations. The systems' interfaces are often prototypic and adapted from conventional two-dimensional graphical human-computer-interfaces. Interfaces remain limited to an extension of existing concepts without exploiting their real potential. A better integration of new concepts for training, for system design and for other future applications by including the capabilities of systems in an early conceptual stage would be desirable. For this, the HSI has to be ergonomically designed on different levels, including the pragmatic, semantic, syntactic, and even lexical level.

It turns out that the ergonomic design of HSI is an intensifying critical issue. The former NATO Research Task Group on *Human factors in virtual environments (HFM-021)* has identified Virtual Reality (VR) or Virtual Environments (VE) to be advantageous for a close, natural, and widely intuitive interaction by making better use of the human perceptive, cognitive, and motor capabilities. It defined VR *as the experience of being in a synthetic environment and the perceiving and interacting through sensors and effectors, actively and passively, with it and the objects in it, as they were real. VR technology allows the user to perceive and experience sensory contact and interact dynamically with such contact in any or all modalities.*

During its three years work it found that VE have developed into a useful technology for various applications. Most of them were found in product design, product presentation, education, training, and visualization of massive datasets. First experimental approaches of integrating VE in military education and training as well as mission rehearsal, support, and analysis were also identified (NATO RTA, 2001).

Potential future military applications of VE-systems identified in the areas of (NATO RTA, 2003):

- Human-system interfaces in materiel design (virtual prototyping).
- Command, control, communications, computer, intelligence, surveillance, reconnaissance (C4ISR).
- Telepresence, teleoperation and telemanipulation in reconnaissance, surveillance and target acquisition.

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- Realistic and distributed simulation and training.
- Short-term mission preparation, including intelligent synthetic individuals and intended area of operation.
- Mission support as wearable, augmenting technology (including Mixed and Augmented Reality).

In 2003 the NATO Research Task Group on *Advances of Virtual Environments for Human-System-Interaction (HFM-121)* was established in order to update the actual state-of-the-art of Augmented, Mixed, and Virtual Environments (AMVE) and derive recommendations for the further development and application of this technology. Within this group, experts from Canada, Denmark, France, Germany, the Netherlands, Sweden, United Kingdom, and USA are exploring the potential of VE systems as an innovative technology for effective and efficient human-system interaction and to investigate system capabilities in the military domain.

First, a report on the actual state of research and technology within participating nations was compiled. The present technical report subsumes the German part of this compendium by giving an overview over research institutions with a primarily military focus, larger defensive projects including AMVE technology, and over civil applications of AMVE technology.

Generally said, in Germany AMVE research is spread across a diversity of civil and military agencies and institutions. Most military projects concerning AMVE topics are coordinated by the German Ministry of Defence and subordinate agencies. They are submitted to research institutions, academic institutes, and defence companies.

In this area, AMVE is not considered to be a high-level topic on its own. Instead, it always refers to special applications and larger defence program. A key domain is traditionally simulation in military education and training. Another domain is design of military materiel, especially in connection with visualization, ergonomic analyses and computer-aided design. Innovative approaches of applying AMVE technologies as an innovative HSI and for teleoperation also came up recently. These domains widely interfere with academic and civil research so that there is a close connection and exchange of knowledge with academic and civil research projects. *Dual-use* has become a common term for characterizing this sharing of results across domains.

This compendium summarizes current military projects including AMVE topics in Germany. Other activities in military simulation, for instance flight or tank simulators, were intentionally left out because they were not within the focus of the NATO RTG. Hence, a technology-based approach of differentiating between AMVE and traditional simulation will be given in chapter 7.1. This report includes three parts. First, studies and activities of institutional research and within defence industry are presented. Chapters 2, 3, and 4 handle this part. Second, main military projects are described briefly in chapters 5 and 6. Finally, in chapter 7, the results of a questionnaire survey on civil AMVE activities in Germany are depicted.

1.1 References

NATO RTA (2001): *What Is Essential for Virtual Reality Systems to Meet Military Human Performance Goals?* Meeting Proceedings RTO-MP-058. Neuilly-sur-Seine: NATO RTA.

NATO RTA (2003): *Virtual Reality: State of Military Research and Applications in Member Countries.* Technical Report RTO-TR-018. Neuilly-sur-Seine: NATO RTA.

2.0 RESEARCH INSTITUTE FOR COMMUNICATION, INFORMATION PROCESSING, AND ERGONOMICS (FGAN – FKIE)

T. Alexander

2.1 Areas of Interest

- Providing scientific and technical expertise for the German Ministry of Defence and subordinate agencies in the area of C4ISR and innovative HSI.
- Applied research in the area of human factors in military AMVE-Systems.

2.2 Current Research Projects

2.2.1 Applicability of AMVE Technology as Tactical Situation Display (TSD)

The general goal of this project is to develop recommendations for the applicability and usability of stationary and wearable AMVE-technology as advanced tactical situation display of C4ISR systems. The results are included into the development of different prototypes for such display systems. Examples of these are shown in Figure 2-1.

Figure 2-1: Powerwall TSD, Electronic Sandtable, Portable TSD for Dismounted Soldiers.

The designs take into account changes of demands on today's C4ISR systems. Within the scope of future scenarios there will be a high demand on detailed and actual information in C4ISR. It is often (and falsely) inferred that more information always leads to better tactical decision-making and higher mission success. High-tech data acquisition, transfer, and pre-processing will enable the military commander to collect a huge variety of diverse information about the current situation. But this massive quantity of information is also risky; especially in time-critical situations with tactical decision-making under stress relevant information is likely to be overseen. This leads to wrong decisions with far-reaching, sometimes fatal consequences. It can be avoided by making better use of the human perceptive, cognitive, and motor capabilities. AMVE technology can be applied here and is very promising already.

The human factors have to be considered as early as possible when designing and evaluating new display systems. Thus, detailed research on the display system itself, e.g. on characteristics of the display (stereoscopy, head-tracking, resolution, ocular stress) and interaction type (relative/absolute interaction, device, input signal gain) and their effects on human performance, as well as research on the kind of information visualization itself (possibilities for visualizing time tracks and uncertainty) are carried out within diverse projects in this field.

The results are integrated into prototypic designs of AMVE tactical situation displays for the tactical decision-making on different military commando levels, from operational to tactical command hierarchy.

2.2.2 Visualization of Massive Amounts of Abstract Data

The technologic and thematic development in the area of surveillance and intelligence is leading to growing amounts of inhomogeneous information and to changing analysis procedures. While in the past analogue radio networks allowed a clear distinction and localization of transmitting and receiving unit this is not possible with upcoming worldwide, distributed, digital communication networks. Especially with growing demands coming along with asymmetric warfare it is more important to sort out relevant information out of free-speech text messages, detect correlations to other messages, and to visualize the results of these pre-analysis in order to support the intelligence analyst.

Because of the huge amount of messages and the natural way of displaying information, it was decided to use AMVE technology as display. By integrating models of the human spatial processing memory general guidelines for visualizing inhomogeneous abstract information are being derived and implemented into a prototype display system. As shown in Figure 2-2, this system is scaleable from desktop-VR for today's use to a more sophisticated cooperative VE-system for future applications.

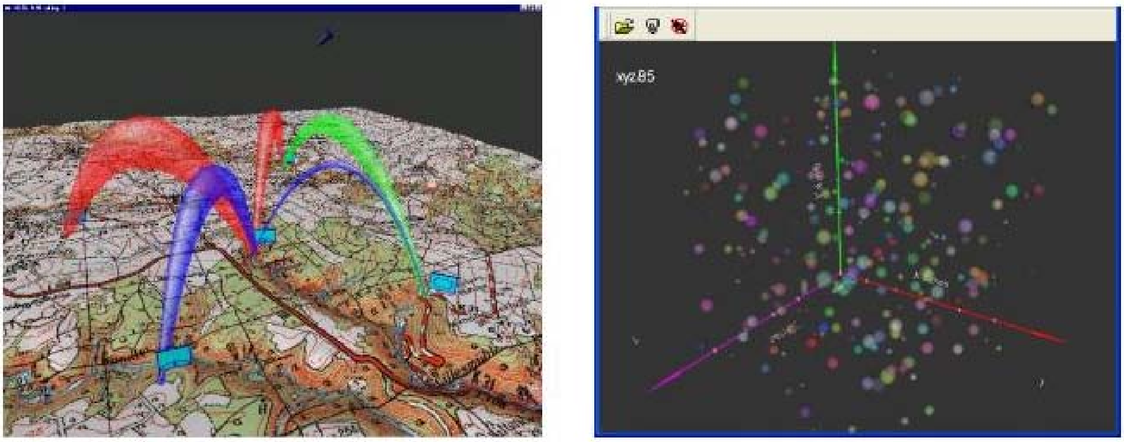

Figure 2-2: Information Visualization on Desktop Display (left) and Within an Immersive VE (right).

2.2.3 Infantryman of the Future

The Infantryman of the Future (Infanterist der Zukunft – IdZ) is a large project succeeding the Soldier 2000 and Soldier 2010 projects of the German Ministry of Defence. In a long-term approach, IdZ includes augmented reality technology to support the dismounted soldier with actual tactical information in his mission. Synchronously, the soldier collects data and enters it into a C4ISR system.

In cooperation with the central institute for medical service of the German armed forces (ZInstSanBw) a realistic scenario for determining performance tests and trials is to be built up. In this connection, a VE-system is used to create realistic scenarios and evoke physiological and mental workload.

2.2.4 Teleoperation of Unmanned Semi-Autonomous Vehicles

Remotely piloted vehicles (RPV: UGV, UAV, UCAV, UUV) are of growing importance for present and future military scenarios. The supervisory control of RPVs represents a cognitively highly demanding task for a human operator. To maintain required levels of situation awareness (SA) an operator must process and respond to multiple complex information streams in real-time. Therefore, the human-RPV-interface plays a key role in enabling an operator to effectively control an RPV with respect to mission requirements. AMVE-based user interfaces have the potential to overcome limitations of presently used

2D-interfaces. Significant amounts of information provided by RPVs, e.g. sensor data, includes georeferenced data, and can therefore take advantage from AMVE systems.

2.3 Results Achieved to Date

VE activities at FKIE/EFS have originally started with usability studies on VE for ergonomic workplace design and analysis. They were found to be advantageous for rapid prototyping applications. At a very early design phase, CAD-models of products could be visualized and examined as if they were real. Improvements were easily possible and the effects could be visualized immediately.

With respect to future tactical situation display a first prototype for applying VE technology, the Electronic Sandtable (ElSa) testbed, was designed and developed. Its concept is based on the sandtable metaphor, which models the working procedures of a traditional sandtable as used frequently in military tactical education. Geographic data and dynamic tactical situation data are stereoscopically displayed on a horizontal surface creating the illusion of a three-dimensional landscape. A self-developed software framework handles rendering. It facilitates rendering of common web3d-scenegraphs, geo-referenced C4ISR-data, and intelligence information on a heterogeneous computer clusters. Several experiments on the sandtable display system were carried out to optimize parameters of the viewing model and for interaction.

Because the original ElSa testbed was based on a rather (expensive,) bulky display technology, alternative displays with higher availability and mobility were built up recently. A low-cost approach uses the same software but a vertical projection surface with standard PC mouse and speech input for interaction. The setup is far more mobile and can be used for different types of command posts. It is based on today’s IT-technology and enhances standard tactical planning procedures – especially tactical situation presentations.

With the third system, which uses Mixed Reality procedures and is called MR-ElSa, mobility is even stronger enhanced. Wearable IT-technology and head-mounted displays offer a system’s applicability “in the field”. The system is to be used by small operational units just before the mission starts. Common software packages were included into the VE-framework and a prototype system has been developed und built up. Interaction procedures are currently being implemented for further research on HIS with this display.

2.4 VR R&D Laboratory

- Graphics / Rendering
  - SGI Onyx 2 InfiniteReality 2 Rack
  - Inhomogeneous COTS PC cluster, diverse NVIDIA Geforce graphics cards (permanent updates)
  - Xybernaut wearable computer
- Visualization
  - *Virtual Workbench* (stereoscopic horizontal projection) with CRT-projectors
  - *Powerwall* (stereoscopic vertical projection) with LCD-projectors
  - Diverse *Daeyang Cy-Visor* low-cost stereoscopic head-mounted displays (HMD) with self-developed “video see-through” option
  - Stereoscopic *Trivisio ARVision3D* HMD
  - *MicroOptical AV-1*
  - *NVisor SX*

- Input Devices
  - Electromagnetic *Ascension Flock-of-Birds Tracking System*
  - Diverse Interaction devices
  - Optical *ARTrack System*
  - *CyberGlove*
  - *Wacom Input Tablets*
  - *VOCON speech recognition*
  - *Space Mouse*

3.0 EADS DEUTSCHLAND GmbH, MILITARY AIRCRAFT

L. Vogelmeier

3.1 Areas of Interest

- Enhancement and customization of Virtual Environments (VE) for use in System Development with focus on Human-Machine-Interface (HMI) development and maintainability evaluations.
- Building up VE-based training devices with focus on procedure training for airborne systems and virtual flight training.
- Defining fields of applications for the operational use of VE in airborne systems and for airborne systems.

3.2 Current Research Project

3.2.1 Virtual Reality for Development, Manufacturing, Maintenance and Training

This project is a shared research project inside EADS N.V with EADS Deutschland GmbH, Military Aircraft in lead.

The main objective of this project is to enhance the VE-Technology to fit the special requirements for development, manufacturing, maintenance and training.

The project is divided into three main work-packages:

1) Realistic and Real Time Capable Light Simulation

The illumination of cockpit or passenger area of an airplane is of high importance for low workload of the crew and convenient travelling of the passengers. Many constraints for the illumination are pre-defined in early stages of development, for example by the basic geometry of the aircraft fuselage or the position of the windows and illuminating elements. Therefore, an early consideration of the illumination of the product is necessary for an efficient development process. To achieve and to keep development iteration cycles short, the use of computer simulation of the illumination is mandatory. Techniques must be found and implemented that provide a computer based light simulation that is comparable to the real world and enable interaction in real time.

2) Integration of Real and Virtual Humans into VE

It is essential to use computer-simulated data in a most efficient way to decrease time and costs for product development. For this reason it is necessary to find ways to merge human characteristics (of developer, operator, customer of the product) and computer data. The main aspect is to learn and understand how the human will act and sentence the future product. Two different concepts are required for this. The first is to simulate the person within the VE as an avatar, and the second is to integrate a real person into the VE. The use of avatars facilitates, for instance, the opportunity to generate test persons that are not available for ergonomic studies in reality, to simulate crowds, or to make assessments in dangerous environments without endangering real persons. Real persons are still required to give feedback about sensations like comfort or discomfort, to investigate stress, or to validate the data generated by assessments with the avatars.

3) Integration of Complex Simulations in VE

The objective of this work package is to control VE by complex simulations. The target applications are the simulation of a full functional aircraft cockpit for pilot training or for testing the Human-Machine-Interface (HMI) concept of the cockpit, to visualize the behaviour of crowds under special circumstances, e.g. the evacuation of an airplane after an emergency landing or the simulation of soldiers under combat situations. Therefore, large amounts of information must be exchanged between the VE-system, which provides visualization and interaction, and the simulation software, which generates and handles the underlying data.

3.3 Results Achieved to Date

- Successful integration of Virtual Reality in the cockpit development process for assessments of static cockpit geometry and layout, based on a mixed mockup system. First adoption of developed techniques in the Tornado program in 2002.

Figure 3-1: Virtual Cockpit.

- A first demonstrator model of a mixed mockup based virtual flight simulator (with restricted functionality) was implemented in 2000 and presented at several air shows. First prototype of complete cockpit simulation in VR was accomplished in 2003.

Figure 3-2: Mixed Mockup Flight Simulator.

- Evaluations of VE-based maintainability assessments with virtual prototypes have been performed. First adoption of defined methods will start in 2004.

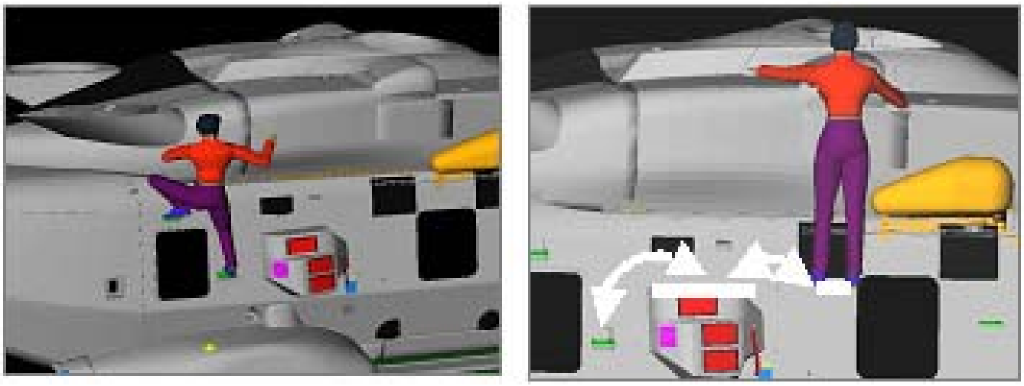

Figure 3-3: VR Maintainability Assessment.

3.4 VR R&D Laboratory

- Graphics / Rendering
  - SGI Onyx 2 InfiniteReality 2 Rack
  - Inhomogeneous COTS PC cluster, diverse NVIDIA and ATI graphics cards
- Visualization
  - Vertical Back Projection (active stereo, CRT-projector, One-Side-CAVE-Mode)
  - HMD *Kaiser XL50*
  - HMD *NVISION Datavisor HiRes*
  - 4-Side Cave (start of operation planned mid of 2004)
- Input Devices
  - Electromagnetic *Polhemus Fastrack System*
  - Ultrasonic *Intersense IS-900*
  - Optical *ARTrack System*
  - *CyberGlove*
  - *Flying Mouse*
  - *DaimlerChrysler speech recognition*
  - *Space Mouse*

4.0 IABG mbH (DEPT. "NETWORKED SIMULATIONS" AT MEPPEN)

F. Reiners

4.1 Areas of Interest

- Interoperability of simulation systems (interoperability between simulation systems alone and between simulation systems and other systems, e.g. C2-systems).
- Application of VE techniques (mainly improvement of user interfaces, e.g. for simulation systems).

4.2 Current Research Projects

4.2.1 Ergonomic Investigations with VR Techniques

The aim of this project is to find out if (and how) it is possible to use CAD data of combat vehicles of the German army for visualization purposes VE. This kind of visualization is considered to be very useful for the following reasons:

1) Ergonomic investigations (e.g. of the interior of a vehicle) can be done already in very early design phases, well before real prototypes are built.
2) The areas of free sight for the driver of the vehicle or for other persons, e.g. looking out of the hatches, can be examined, without the need for cumbersome and expensive measurements using the real vehicle.
3) The derivation of requirements for new military equipment can be supported enormously by coupling VE systems to simulations of the appropriate environment. For combat vehicles, this environment can be represented by combat simulation systems.

Usually, the direct use of CAD data for VE purposes fails, because the number of polygons that are needed for the proper description of the geometric extension of a vehicle is very huge, and an acceptable visualization e.g. in an HMD is not possible anymore. Instead, a significant reduction of the number of polygons is required.

The available CAD systems do not allow the automatic conversion of CAD data into formats that are used in VE systems. Therefore, in this project several steps were examined that are useful in performing this conversion. Figure 4-1 shows different sequences of steps that can be followed to reach this conversion.

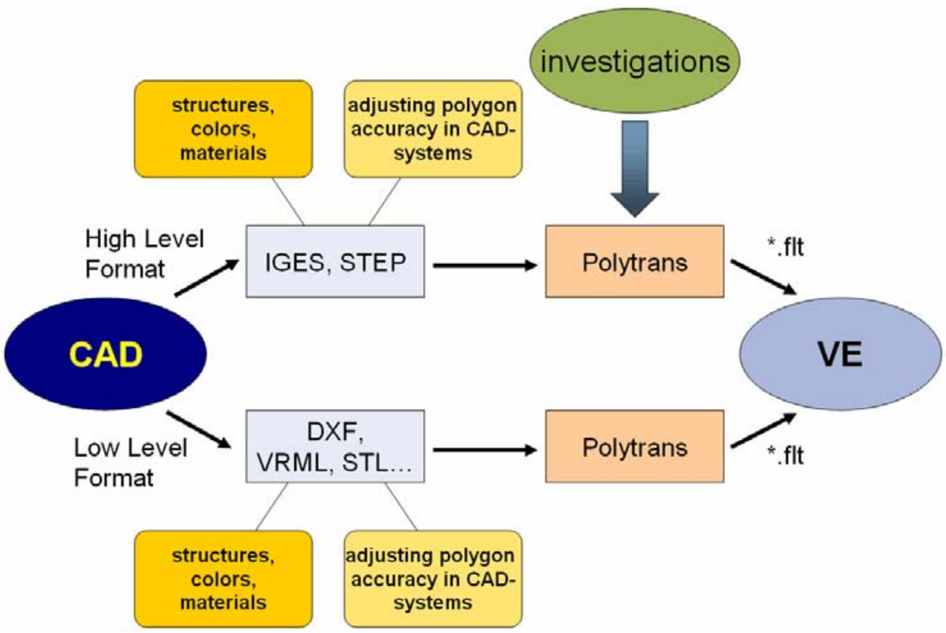

Figure 4-1: Possible Sequences for Converting CAD Data into VE Formats.

First ergonomic examinations of areas of free sight within the armored transport vehicle BOXER were done by using an HMD connected to either a mechanical or magnetic tracking system. Figure 4-2 shows a simulated view into the interior of a BOXER. The VE data have been derived completely from the CAD data as provided by the manufacturer of the vehicle.

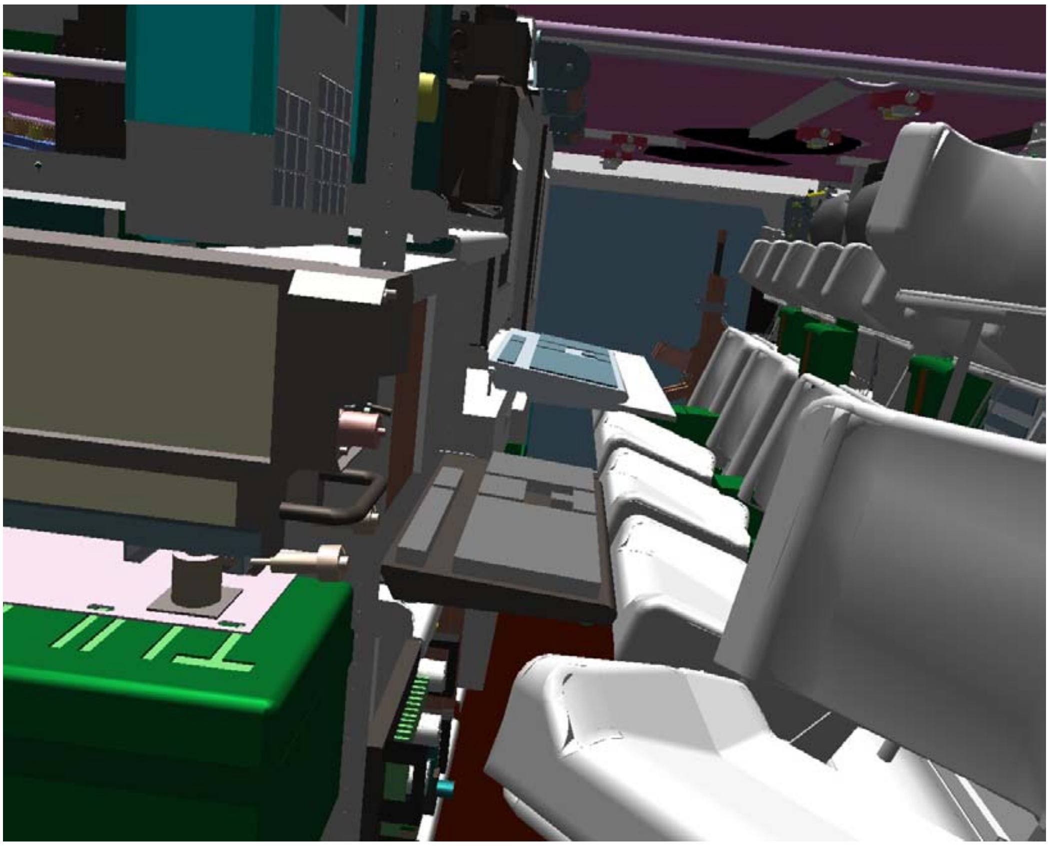

Figure 4-2: Simulated View into the Interior of a BOXER with VE Data Derived from CAD Data.

4.2.2 Coupling of VE-Systems with Combat Simulation Systems

As already mentioned above, it makes sense to join VE-systems with combat simulation systems. It was decided to perform this coupling in a two step procedure:

1) Coupling of an HMD to a driving simulator;
2) Coupling of the driving simulator to a combat simulation system.

In this study, available systems were used: An experimental, component-based driving simulator and the combat simulation system PABST 2000 by IABG.

An HMD can be seen as a special graphical monitor where the projection is dependant upon the position of the eye of the user captured by a tracking system. In the experimental driving simulator, it can be modified by keyboard inputs. The main focus of this experiment was to calculate the correct view shown in the HMD. This view depends on the right superposition of:

1) The position and orientation of the HMD (derived from the tracking system);
2) The position of the eye point, relative to the vehicle (derived from parameters of the driving simulator); and
3) The position of the vehicle within the synthetic terrain (derived from the combat simulation system).

Figure 4-3 shows an example of a picture as seen by the HMD, compared to the corresponding map of the combat simulation system.

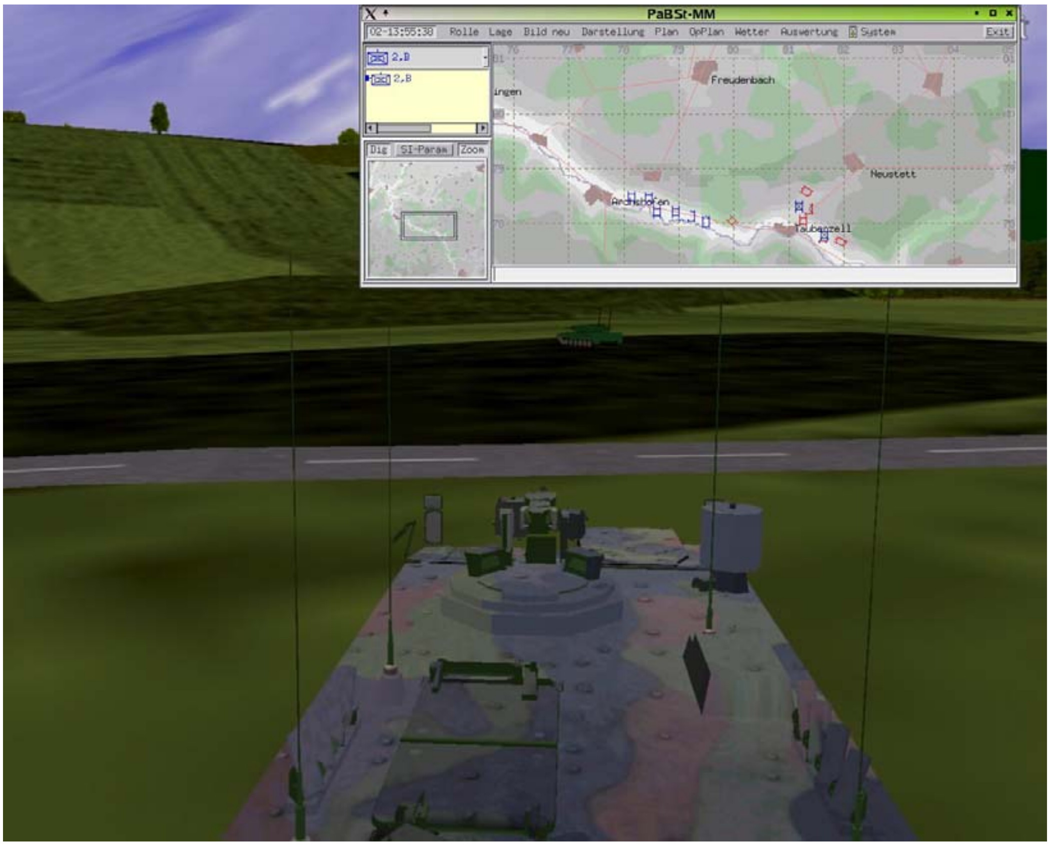

Figure 4-3: View into a Virtual Environment. The corresponding visualization of the combat simulation system PABST 2000 is shown in the insert.

4.3 VR R&D Laboratory

- Graphics / Rendering
  - PC, NVIDIA Geforce graphics cards
- Visualization
  - *Stereoscopic HMD NVISOR SX*
  - *Monitor*
- Input Devices
  - Electromagnetic *Ascension Flock-of-Birds Tracking System*
  - *Mechanical Shooting Star Technology ADL-1*
  - *Joystick*

5.0 CoCBT (KoCUA) – CO-OPERATIVE COMPUTER-BASED TRAINING FOR THE AMPHIBIAN M3

5.1 Background

CoCBT is a training device for the German Amphibian vehicle M3. The operational spectrum of this trainer covers driving practice on land and water including coupling manoeuvres, building bridge stumps and ferrying operations with large ferries. The instructor can control the exercise conditions by changing the variable parameters (e.g. wind, weather, water velocity, technical, and tactical incidents). Real crossing sites on the rivers Main and Weser have been used as a basis for the virtual exercise areas. A wide variety of wheeled and tracked vehicles can be used by the crossing troops.

The operation of the M3 amphibian requires the co-operation of several crews, for example when coupling amphibians to build a ferry. The previously available training tools, which are CBT program and digital teaching aid, were primarily designed for single-place training. However, a comprehensive amphibian training requires a team-oriented approach. CoCBT focuses on this approach. Figure 5-1 shows the setup of CoCBT.

Figure 5-1: CoCBT Amphibian M3 Training Facility.

5.2 Technology

The CoCBT Amphibian M3 training program facilitates single individual and team training. In a VE, which is implemented in a PC network, it is possible to train a team of up to four students in the operation of the amphibious vehicle M3. Consequently, CoCBT covers the complete spectrum of the amphibious training. The crew is able to exercise throughout the whole year, under controlled conditions, and independently from the otherwise mandatory availability of staff and equipment.

The whole virtual training situation is presented on three monitors with a 120° panoramic view. An additional, lower monitor is used to show the necessary handling functions (e.g. control stand). The crewmembers control the action by a PC-mouse, keyboard and the original master pilot (which is used for steering on water). The ferry commander gives hand signals, which are depicted by the system with the use of data gloves and a tracking system. An animated character presents the hand signals synchronously in the virtual world.

The CoCBT Training System consists of workstations with several PCs, which are linked to each other in a network. The educational network helps the instructor supervise the progress of the exercise.

For exercise assessment a recording system is available, which can be used for observing the training at any time. The recording also supports the instructor's follow-up of the exercise. The complete training system is based on a scalable technology, which allows for example, to add more workstations or to expand the panoramic view of the virtual world to 360°. This training platform can also be used in the future for other systems.

5.3 Delivery

The CoCBT training system was officially presented to the Armed Forces Engineers in Minden in December 2002.

6.0 ADVANCED AIR DEFENCE TRAINING SIMULATION SYSTEM (AADTSS) – VR STINGER TEAM TRAINER

6.1 Background

In the past, team training for the STINGER weapon system was done in stationary, large-scale dome trainers. Changing requirements, especially growing demands on mobility and transportability, made a modernization of the trainers and the application of new technology necessary. For the layout of the new trainers immersive VE-technology was utilized to allow a commander and a gunner cooperative training of STINGER handling. The system had to cover 350° horizontal and 130° vertical field of view, visualize multiple targets and effects and facilitate long-range aircraft detection and identification. In Figure 6-1 the system is illustrated.

Figure 6-1: VR STINGER Team Trainer.

6.2 Technology

The AADTSS simulator is integrated in an extensible container. Both, commander and gunner are equipped with Head-Mounted-Displays (HMDs) for visual display of the VE. For long-range aircraft detection/identification a high resolution was required and the HMD is capable of a maximum resolution of 1.280 x 1.024 pixels per eye. Because of better contrast and separation of surrounding light, the HMDs are without see-through option.

The team members have to co-operate with each other acoustically and optically, but due to the HMD they cannot see each other. By modeling both as avatars this problem was solved.

The commander's actions are tracked by an inertial tracking system, whereas the gunner is tracked by an optical tracking system. For safety reasons, both team members are encircled by handrails. This solution was necessary because of the HMDs without see-trough-option.

A further aspect was the database for training. The generation of databases is based on stereoscopic photos. It allows the generation of scenarios, targets and flight paths and is independent of the simulator. The system consists of one workstation, the stereo-camera-system and one control-PC.

6.3 Delivery

After an initial successful troop trial phase in 1997, a first system was delivered in 2000. A second system has been ordered from the German Air Force recently. Whereas the first system has been integrated into a mobile container, the second will be modified for inside building uses.

7.0 SUMMARY OF CIVIL AMVE RESEARCH

7.1 Background

Civil AMVE research activities in Germany are as multiple and manifold as in other countries. Most of these activities have their origin in computer sciences and computer graphics and are still positioned here. But recently, AMVE technology has become a tool for research in other areas and applications as well. This chapter explained the general background of civil AMVE research. Furthermore, the criteria for choosing participants in the survey, as well as the send and return of questionnaires are described.

7.1.1 General Background

Research on Virtual Reality (VR) and its applications started around 1980. VR was originally considered as an innovative visualization concept for system design and rapid prototyping. The premier goal of a natural interaction and an "intuitive" use made it a topic of ergonomics and human-computer-interaction at a very early state. Due to lacking performance it took several years until a reasonable use and application became possible. At first, among other reasons because of the expensive equipment required for research, only a relatively small number of institutions were on the topic. At that time VR turned out to be a highly innovative and technology-driven topic, which's true application areas were still to be determined.

Research was divided into then: On the one side there was application-oriented research (focusing on workplace design, medical applications, teleoperations etc.) and on the other side more basic, fundamental research on AMVE on its own (computer graphics, rendering etc.). With growing availability of VR equipment, a broad spectrum of academic, federal, and industrial institutions started work in this publicity topic. Today, the term VR has become widely used for each and everything, so that the term Virtual Environments (VE) has become more popular in the scientific world.

Due to higher technological demands, research on Augmented Reality (AR) and Mixed Reality (MR) came up slightly later. Both have been influenced and supported largely by the German automotive industry. A special goal is application of AR for development, production and maintenance of complex technical products.

7.1.2 Criteria for Choosing Participants

A main problem for setting up this questionnaire was to limit it to relevant activities in AMVE only. Traditional simulators, as frequently used by German automotive industry and research were intentionally left out. To distinguish between a traditional simulator on the one hand, and a VE-system on the other was difficult because both overlap widely and there is large parallelism between them.

At a first approach, VE is considered to be a part of simulation and not vice versa. It is well known that there are arguments for an opposite structure as well. Nonetheless, for this report the definition of VE given in the introduction and the notion within the scope of the RTG are strictly referred to. Thus, simulators were to be left out.

Likewise simulators, VE systems visualize synthetic, computer-generated databanks. Likewise simulators, VE evoke a feeling of being a part of the simulation. But unlike simulators VE simulate stimuli to a greater amount by means of special devices. In a simulator the direct surrounding of the user still remains the (real) original equipment (i.e. a cockpit of a flight simulator still is "real" just the outside view is virtual) while in an ideal VE system this would be simulated as well (i.e. by means of haptic feedback). For a VE system the synthetic part of stimuli is considerably larger than for simulators. Consequently, a closer user involvement (including head-tracking etc.) and special hardware is required.

Close user involvement is always subjective and object to vary largely between subjects. For this reason it seemed unpractical to choose it as main criteria. Instead, the specific hardware technology, which is more objective, was chosen to be the main criteria for identifying participants for the survey.

This –very technocratic– approach gave an opportunity to distinguish large-scale from small-scale research activities, because substantial research in AMVE still requires special devices (and expenses). We have chosen availability of head-mounted-displays (HMD), stereoscopic vertical or horizontal projection surfaces (Powerwall, Workbench), or special AMVE hard- and software as the participation criteria. This resulted into the participating institutions referred to in the following chapters.

7.1.3 Send and Return of Questionnaires

For this compendium available AMVE technology, application areas, and general areas-of-research were considered to be relevant. The questionnaire attached in the annex was sent out to 44 scientific and industrial institutions in Germany and 7 in Austria and Switzerland. As shown in Figure 7-1, 14 out of these were academic/university, 12 were federal and free research institutions, 13 industrial laboratories and 5 were developers of AMVE systems.

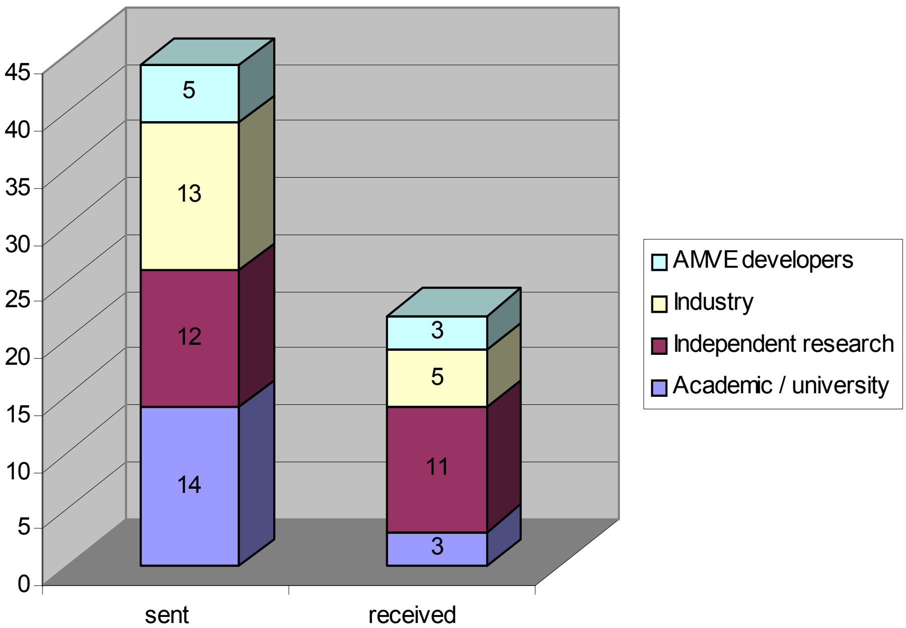

Figure 7-1: Questionnaires Sent and Received.

Twenty-two questionnaires (overall return rate: 50%) were returned. Three (14% returns) came from universities, 11 (92% returns) from federal and free research, 3 (60% returns) from AMVE system developers and 5 (38% returns) from industrial laboratories.

The results derived from the questionnaire returns are summarized in the following chapters. It has to be mentioned that more than a single response was possible at every question.

7.2 Technology

Technology is the backbone of each AMVE activity. Although it can be considered as widely available, technology development has not stopped, and technology trends are likely to affect more general trends in research. Technology includes the computing and graphic platforms, the display system and its modality (visual, acoustic, haptic), tracking systems, and special interaction devices. A further important aspect is software, e.g. operation system, rendering software, supported databank formats, and application-specific software.

7.2.1 Computing Platform

Recently, computing and graphics power of personal computers have tremendously increased. This resulted in growing utilization of PCs in AMVE laboratories. They have widely replaced the specialized, monolithic graphic workstations. Another effect of this development is that research activities and applications of VE technology have increased because of fewer required expenses, though still remaining cost-intensive. The results of the survey are shown in Figure 7-2.

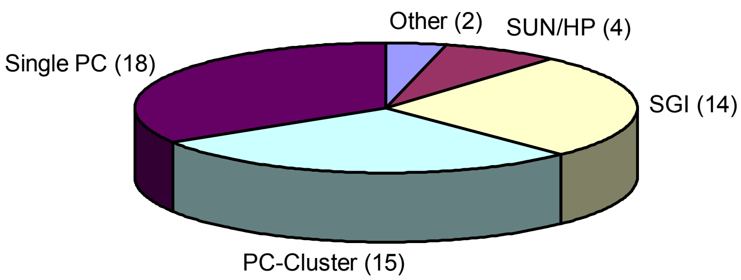

Figure 7-2: Computing Platform of AMVE-Systems.

Single PCs with high-end graphics cards are used in 18 AMVE institutions (82%). By connecting multiple PCs into a cluster, more graphics performance is available. Fifteen (68%) of the participants in this survey follow this direction. High-end graphic workstations from Silicon Graphics Inc. are a part of equipment of 14 institutions (64%). Four (18%) institutions use workstations from SUN or HP, respectively. For AR or MR topics a wearable PC is the most frequently used computer platform (2 cases, 9%). The application of PC increases to 21 laboratories (95%) if it is not differentiated between single or clustered PC. Consequently, all except for one single lab with a graphics workstation at least additionally use PCs in their AMVE-setups.

7.2.2 Visual Display

The visual display plays an important role for the applicability of an AMVE system because most of the environmental stimuli are perceived by the optical sense. Figure 7-3 shows the visual displays present at participating institutions.

As expected, most participants in this survey (15 cases, 68%) make use of monitor displays. Thirteen laboratories (59%) are equipped with HMDs which facilitate a total immersion into the VE.

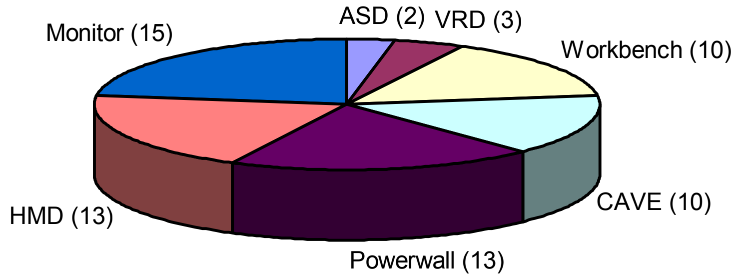

Figure 7-3: Visual Displays.

The diverse projection-based systems serve as visual display in 17 cases (77%). Most frequently a vertical projection surface is used (13 cases, 59%). Other projection-based systems (horizontal projection surfaces, and multiple surface projection systems) are each present in 10 laboratories (45%). These systems vary strongly in size (from 1 to 12 m) and number of projection planes (1 to 6).

In contrast to this, virtual retinal displays (VRD) (3 cases, 14%) or autostereoscopic displays (ASD) (2 cases, 9%) are only rarely found.

For projecting-based systems liquid crystal display (LCD) projectors are used most frequently (6 cases, 38% of projection-based systems). They facilitate a very bright presentation with high contrast and are relatively low-cost. Due to technical limitations they require a time-synchronous stereo-separation resulting in at least two projectors per projection surface. Cathode-Ray Tube (CRT) projectors which are used in 5 labs (31% of projection-based systems) work with higher framerate and allow time-alternating stereo-separation. Nonetheless, their projection is darker and they are usually more expensive than LCD projectors. Four labs (25% of projection-based systems) work with digital light processing (DLP) projectors that offer a higher projection quality. Three labs (21% of projection-based systems) use Direct Driven Image Light Amplifiers (D-ILA) with higher resolution and high brightness. Four participants using projection-based systems did not respond to this question.

Monitors and projection-based displays require glasses and devices for stereo-separation. These can be either time-alternating or time-synchronous. Time-alternating shutterglasses are usually found at monitors or when CRT-projectors are used. Twelve labs (55%) are equipped with these devices. In contrast to shutterglasses time-synchronous anaglyph (color) or polarization filter glasses are light-wear and cheaper. Polarization filter glasses are used in 15 labs (68%) while anaglyph glasses, which do not allow color presentation, are used in a single lab (5%) only.

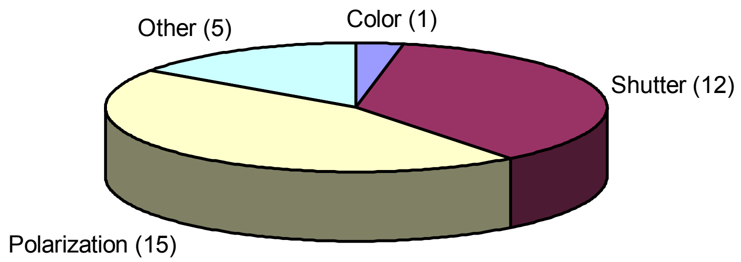

Figure 7-4: Devices for Stereo-Separation.

7.2.3 Acoustic Display

Multi-modality enhances the effect of immersion into the VE. For this, acoustic displays serve as an extension to visual displays. Acoustic displays are present in 15 institutions (71%). Nine labs (41%)

are equipped with stereo outputs and 8 (36%) use surround sound systems. Two participants in the survey have both available. Two institutions use other acoustic displays (binaural, 3D audio).

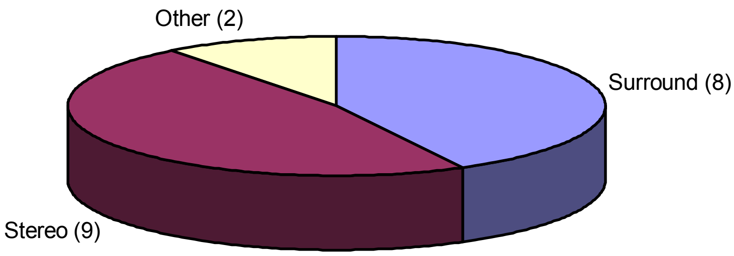

Figure 7-5: Acoustic Displays.

7.2.4 Haptic and Kinesthetic Displays

A further output modality used by AMVE-systems is haptics. Haptics is especially essential for fumbling, reaching, and grasping. A close, natural interaction with virtual devices becomes difficult without haptic feedback. Equipment for experimental haptic feedback is available in 10 institutions (45%), as shown in Figure 7-6. Mock-Ups made either from wood or other materials prepare a very accurate haptic feedback but are usually not very easy to modify. They are used in 5 labs (23%). Two participants (9%) make use of vibrating elements, and 1 (5%) use stepper motors or linkages. Four others (18%) possess PHANTOM devices that use stepper motors as well.

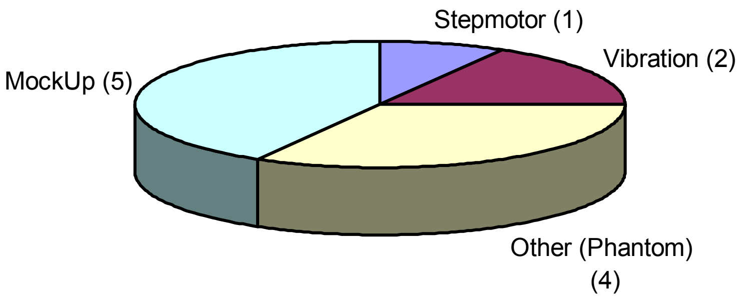

Figure 7-6: Haptic Displays.

Kinesthetics comprises the sensation of self-motion. It is implemented mostly by means of motion platforms, which simulate accelerating forces for the operator. Three labs (14%) are equipped with such motion platforms.

7.2.5 Tracking Systems

Receiving and processing operator inputs is obviously important for interactive systems. Tracking systems facilitate tracking of operator's view point position and orientation as well as the position and orientation of input devices. Tracking has to be real-time to minimize system lags and dizziness. Additionally, they have to be accurate enough to prevent display errors.

Figure 7-7 shows that electromagnetic tracking systems are widely used (16 cases, 73%), being followed by optical tracking systems (14 cases, 64%) and inertial systems (4 cases, 18%). Two labs (9%) make use of ultrasonic devices, and one possesses equipment for gaze capture. Two participants gave no answer to this question or do not make use of operator tracking. Again, the majority of labs rely on more than just one method. However, it is not clear whether methods are actively combined or just used for different setups.

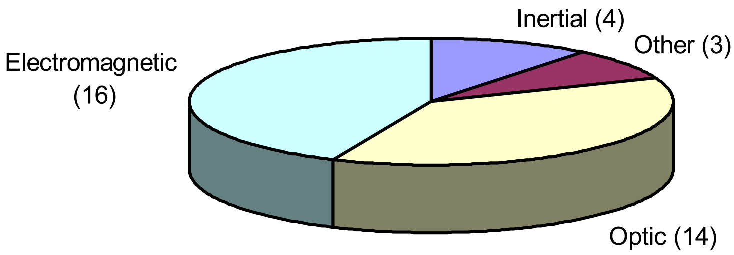

Figure 7-7: Tracking Systems.

7.2.6 Interaction Devices

Unlike conventional human-computer-interaction an intuitive, natural HSI requires special input devices. They vary between rather simple devices like mice or trackballs to highly sophisticated like 6-degree-of-freedom (6-DOF) controls or pointing devices. The proportions for the most common devices are shown in Figure 7-8.

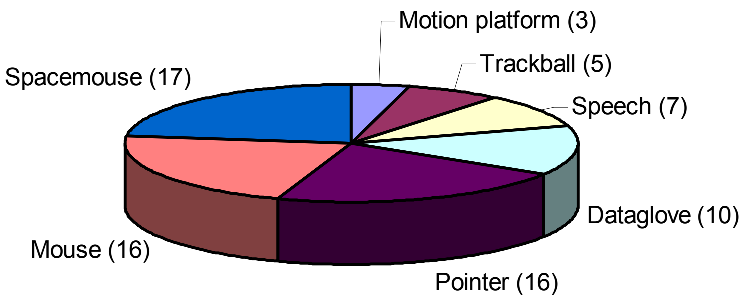

Figure 7-8: Interaction Devices.

Most frequently, a 6-DOF Spacemouse or comparable devices are used for 3D HSI (17 cases, 77%). Sixteen labs (73%) make use of conventional mice with just 2 degrees of freedom. The technologically identical trackballs are found in 5 labs (23%).

Pointing devices also requiring a tracking system are reported by 16 labs (73%). Five participants (23%) did not mention this devise despite have tracking systems available. This may hint at a misunderstanding of the question. Therefore, the actual percent of pointing devices can be considered as higher. Data gloves or derivatives make gesture input possible and allow a very natural pointing – simply with the hand gestures. They sometime include vibro-electric elements for haptic feedback (see according section 7.2.4). Ten of the participants' labs (45%) are equipped with these gloves.

Yet, all input devices facilitated a manual operator input – either by controlling a cursor, pointing, or gesture. Speech recognition facilitates acoustic and speech input and introduces a further modality. Speech input is usually combined with other interaction techniques like pointing. Seven institutions (32%) include speech recognition as a further input modality.

In addition to this, mixed mock-ups (see section 7.2.4) frequently use original input devices like knobs or dials as input devices. The Phantom device does not only serve for output, but also for input.

In addition to these commercially available products, several self-developed devices and innovative approaches are used. They include Cubic Mouse, JoJo, Easy2C and others. Special information about these innovative devices can be found on the websites of the according institutes.

7.2.7 Operating System

Hardware and devices described before are the backbone of the AMVE systems, but they would not operate without drivers and other supporting software. They are running on different operating systems. Figure 7-9 shows, that in 14 labs (64%) IRIX, the operating system for Silicon Graphics workstations is installed. The same amount uses LINUX operation system or Microsoft Windows. Only 2 labs (9%) run the UNIX operating system.

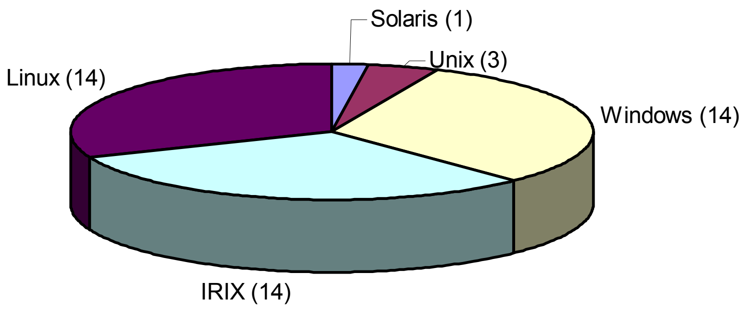

Figure 7-9: Operating System.

7.2.8 Visual Rendering Software

Visual displays and graphic computing hardware require a powerful rendering basis. The proportions of the most common rendering libraries or framework are illustrated in Figure 7-10. OpenGL (17 cases, 77%) is used most often as basis. Extensions of OpenGL, either self-developed or supplied, are implemented in 5 labs (23%). With SGI hardware platforms the software performer is present in 8 cases (36%). DirectX and derivatives serves as rendering basis in 5 institutions (23%).

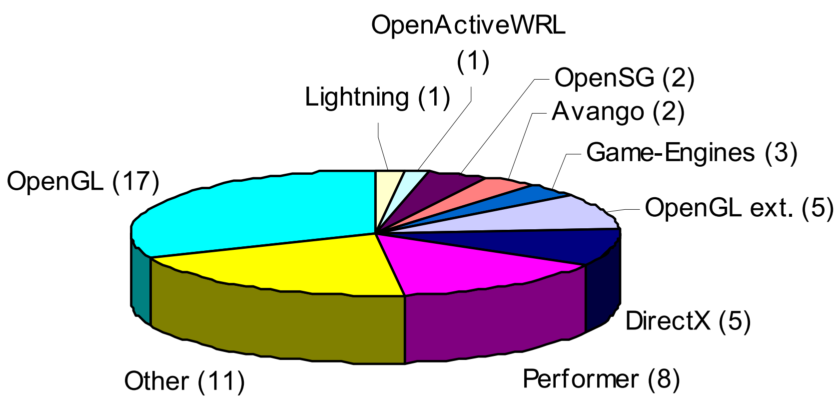

Figure 7-10: Visual Rendering Software.

Further and more specialized rendering software is just used by two labs (OpenSG, Avango) or just one lab (Lightning, OpenActiveWrl), which is usually the developing community of the rendering framework. Applications of rendering machines from game-engines were not reported.

7.2.9 Acoustic Rendering Software

Likewise visual rendering, there are special software frameworks for acoustic rendering as well. Six institutions (27%) report activities in acoustic rendering: 4 (18%) are using DirectX. 2 (9%) use OpenAL as more sophisticated acoustic rendering library.

7.2.10 Supported Data Formats

Virtual Worlds are usually not created online but stored in a special data format. The rendering software is capable to read this format and create a visual output out of it.

Answers in this section were very limited. The software of 5 institutions (23%) supports CAD data formats, and 3 (14%) support VRML as 3D modeling language. Other formats like inventor or Openflight etc. were just reported once. It has to be mentioned that the validity of these answers is not high because of a lot of missing answers (just 10 answers).

7.3 Areas of Application and Research

While hard- and software is the basis application and research gives insights into the actual purpose and intention of AMVE-systems. Due to the high flexibility of these systems, both topics have a broad spectrum. In theory, AMVE-systems can be applied to any possible application. In reality, there are several areas where the use of AMVE-systems is very promising and beneficial. In this chapter the relevant software modules for special applications, research and application areas are described. It is shown, that AMVE-systems, although still a research topics on their own, have changed into an application in recent years.

7.3.1 Application-Dependent Software Modules

Special applications require more specific software modules. These modules can be either single-stand modules, or they are a part of complex framework. In the questionnaire a rough structure of the main application-dependent modules was given. The result of the survey is illustrated in Figure 7-11.

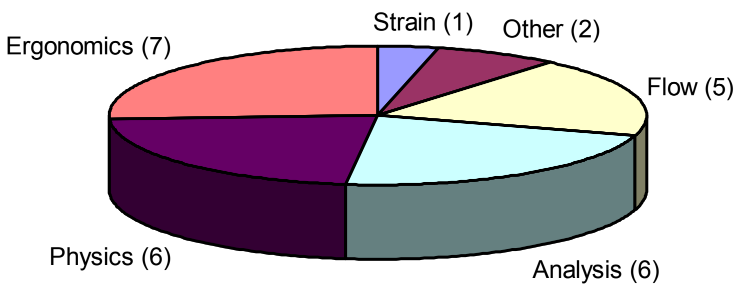

Figure 7-11: Application Software Modules.

For general analysis modules 6 institutions (28%) specified their software. Main modules were specific tools of Bool, CAD, BAF, VD2, ICEM/Surf, AVANGO, IDO Review, and others. Integrated physical libraries (5 answers, 23%) are ODE, Vortex, AVANGO, HAVOK 1.1. Modules for ergonomic analysis of workplace design are available at 7 institutions (32%). This comprises digital human models like Anthropos and RAMSIS as well as specific modules of VD2, AVANGO and IDO-Ergonomics. For CAD-Applications and general applications in manufacturing, strain analysis and analysis of flow are important. Five institutions (23%) answered this question positively. Available modules are within the AMVE-software libraries and packages EnSight, AVANGO, and Covise.

7.3.2 Areas of Research

Despite of upcoming real applications AMVE still remains a research topic and provides the infrastructure for research topics. Only two institutions (9%) did not respond to this question and are considered not to perform research activities in connection with AMVE. The frequency of other research topics is shown in Figure 7-12.

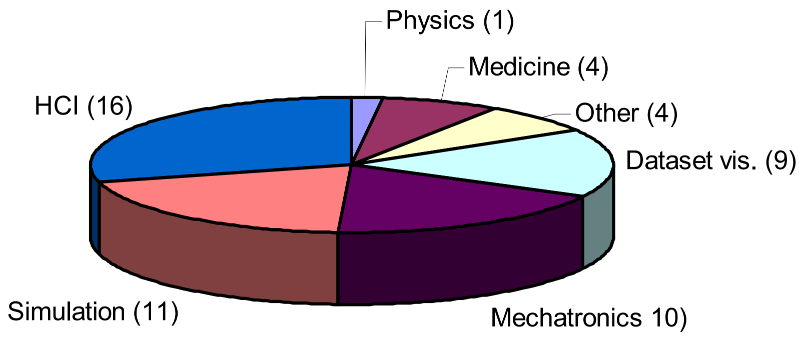

Figure 7-12: Research Topics.

According to this, the most frequent area of research is human-computer-interaction (16 cases, 73%). This meets the expectation because AMVE has been introduces as an innovative HSI and research in this area is required for optimal usability and application in manifold areas.

Other applications make use of AMVE technology as a tool. They are in the area of mechanical engineering / mechatronics (10 cases, 45%) and simulation (11 cases, 50%) of all kinds, but most frequently in combination with mechanical engineering. Nine institutions (41%) use AMVE technology for the visualization of massive datasets. In 4 labs (18%) medical applications of AMVE technology are the main focus. Applications in combination with other sciences like physics (1 case, 5%) or chemistry (no case) can be neglected. Further application areas (1 case per area) are architecture and modeling, storytelling, basic research in perception, and team training.

7.3.3 General AMVE Technological Development

In addition to research in more application-oriented areas, AMVE itself is being developed further on. This is necessary because of changing requirements for experimental setups and applications as well as changing technical capabilities. In total 16 institutions (73%) report activities in general technological developments. As shown in Figure 7-13, software development is the main goal of development. Six labs (27%) develop both, new software and hardware for AMVE. Two labs (9%) develop new hardware and 9 (41%) new software and software modules only.

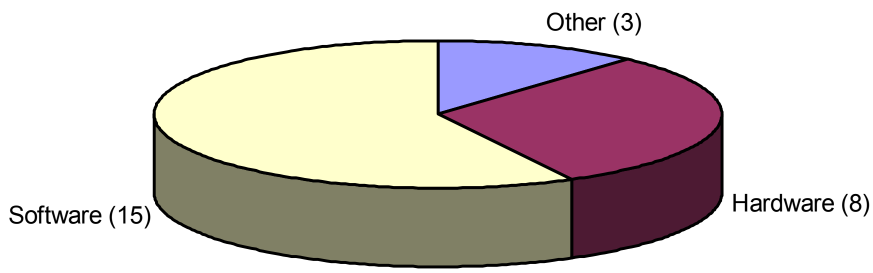

Figure 7-13: AMVE-Technology Development.

7.3.4 Product Design and Development

In product development AMVE technology is used primarily as a tool. In this case, AMVE provides infrastructure for developing a diversity of other systems. Figure 7-14 shows that most frequently industrial manufacturing processes, car manufacturing, and simulation (10 cases, 45%) are reported as application area. The following item, including 7 cases (32%), is product presentation. Five institutions (23%) use AMVE technology for application in architecture, aviation, and product design. Other applications areas are education and training in maintenance (1), automatisation (1), and military applications (1).

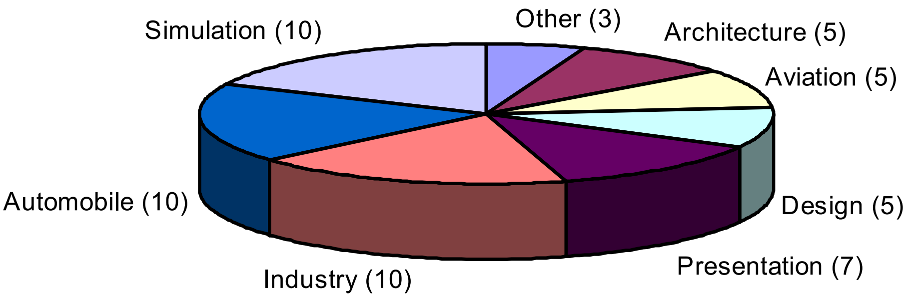

Figure 7-14: Area of Product Design and Development.

8.0 CONCLUSION

The report describes applications and research in institutions and within larger projects in Germany. Furthermore, a brief sketch of technological and thematic characteristics and trends for the civil sector is given. It shows that AMVE systems have evolved from a pure research topic to an application topic and that this trend is about to grow in future.

One obvious finding is the broad usage of PC systems for AMVE activities. Workstations are still used but even then PCs are used as an addition. The use of COTs hardware can be seen in display technology as well. Monitors are most often used, being followed by projection-based systems. Of course, the latter cannot be considered as commercially widely available, but they were strongly affected by dropping prices for LCD projection systems. Moreover, they do not have handling or comfort problems like HMDs. And they make team activities possible; something that is obviously impossible with a single HMD only.

As expected, visual presentation is more frequently present than acoustic or other modalities. However, acoustic is growing and available at several setups.

Tracking is widely done by optical or electromagnetic systems. Interaction devices are manifold and include simple as well as highly complex devices of various kinds.

With regard to software, Window, Linux and IRIX are most common. For acoustic or visual rendering most frequently self-developed software-frameworks or open-source software is used. They usually have benefits for specific applications but are variable enough to adjust them to others.

The main application area is ergonomics and within this, human-computer-interaction. Other areas are simulation, mechatronics, and visualization. Consequently, modules for physics, analysis of various kinds, and flow are available. Considering AMVE systems on their own, software is more often developed than hardware.

Most common application field is simulation, automotive and general industry, and product presentation.

In addition to the national findings, the NATO RTG has identified emerging technologies in one of its recent meetings. All of them will have effects on AMVE technology and its application. This includes:

- Vision (laser-based projection systems, small dome-projection systems, holographic displays, autostereoscopic displays)
- 3D-audio (new real-time software)
- Motion platforms (new pneumatic and electromechanic systems)
- Vibro-tactile elements (haptic feedback)

Seen from an international view, one of the main applications of AMVE technology still remains simulation and training. This is not observed in Germany, but is likely to develop with growing availability of AMVE-systems. This will result into more detailed modeling of the synthetic environment and the development of more realistic simulation environments. It also includes intelligent agents, i.e. behavior models, CGF, virtual combatants and their dynamic behaviors becoming a part of the training environment as well.

A further general trend is based on the falling prices of AMVE hardware. Increased computer power at low cost, wireless networks, shrinking of computer components, and better visual and auditory display systems are contributing to the maturation of these technologies. Potential applications in military operations, as well as training and system design are providing requirements that have spurred the technologies' development. Still most of the attention is drawn on the development of the technologies themselves. However, to be effective in military operations, the technologies must evolve into reliable systems that provide the information that their human users need to accomplish task objectives.

Compared to research on computer architectures, communication protocols, and display devices, there has been relatively little research on the perceptual requirements for displays, HSI issues from a human-factors point-of-view, design of effective training approaches, and measurement of human performance. The fundamental knowledge available today already indicates a large potential of AMVE technology for a broad spectrum of military applications, including: 1) dynamic, task-driven user interfaces for C4ISR systems; 2) telepresence, teleoperation, and telemanipulation in reconnaissance, surveillance, and target acquisition; 3) realistic, distributed military simulation and training; 4) mission preparation en-route, including intended area of operation; and 5) mission support as wearable, augmenting technology for individual operators.

Appendix A: Participating Institutions

We would like to thank the following institutions and persons for their participation and help in the survey.

Bauhaus Universität Weimar
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Volkswagen AG
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Peter Zimmermann

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EADS Deutschland GmbH
81663 München

for providing us with chapter 3

and

Friedhelm Reiners
IABG Dept. "Networked Simulations"
Schiessplatz
49716 Meppen

for providing us with chapter 4.

Information considering chapter 5 (*Co-operative ComputerBased Training for the Amphibian M3*) is based on the internet domain of the project – http://www.kocua.info/.

- Contact for further information: Ray Sono AG Bremen, Otto-Lilienthal-Str. 8, D-28199 Bremen

Information considering chapter 6 (*Advanced Air Defence Training Simulation System*) is based on the www-homepage of EADS – http://www.eads.com/

- Contact for further information: EADS Defence and Security Systems, Business Unit Systems & Defence Electronics, 88039 Friedrichshafen